Analysis of steel-reinforced concrete-filled steel tube columns (CFT) under axial compression and moment

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Abstract

This study presents an investigation into the behavior of steel-reinforced concrete filled steel tubular columns (CFT) using the finite element software ABAQUS. The steel tube provides lateral confinement to the concrete core which results in an increased concrete compressive strength and deformation capacity. The concrete infill, in return, prevents the inward local buckling within steel tubes. The axial load bearing capacity of CFT is thus higher than the summation of axial load-bearing capacities of the concrete core and the hollow steel tube. The axial force P and moment M interaction diagram is generated.

1. Introduction

The aim of this investigation is to employ the nonlinear finite element program ABAQUS to perform numerical simulations of CFT columns subjected to concentric and eccentric compressive loads. To achieve this goal, proper material models for steel rebar, steel tube and concrete have been adopted. First, the P-M diagram of a pure reinforced column without a tube is generated using spColumn, reinforced concrete column design and analysis software. Then three cases are executed using ABAQUS: a pure reinforced concrete, a reinforced concrete column with a steel tube using unconfined concrete material property model and a reinforced concrete column with a steel tube using confined material property model. Finally, a comparison of axial forces P and moments M is studied.

2. Model description

2.1 Geometry

In this study, the steel tube and concrete core are defined as solid elements, while the rebar reinforcements are truss elements. The geometry of the column is 12 × 12 inches, and the thickness of the steel tube is 0.5 inches. The reinforcements are 6-#8 bars, with #3 ties. The column is 12-foot long. It is illustrated by Fig.1.

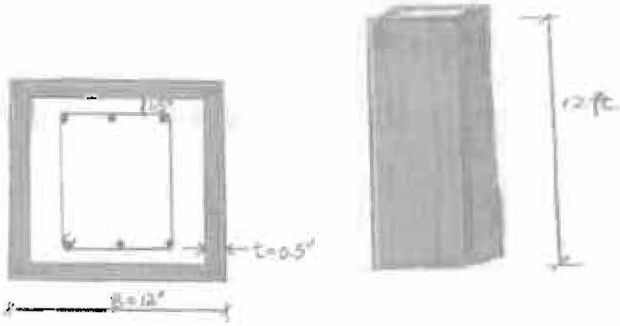
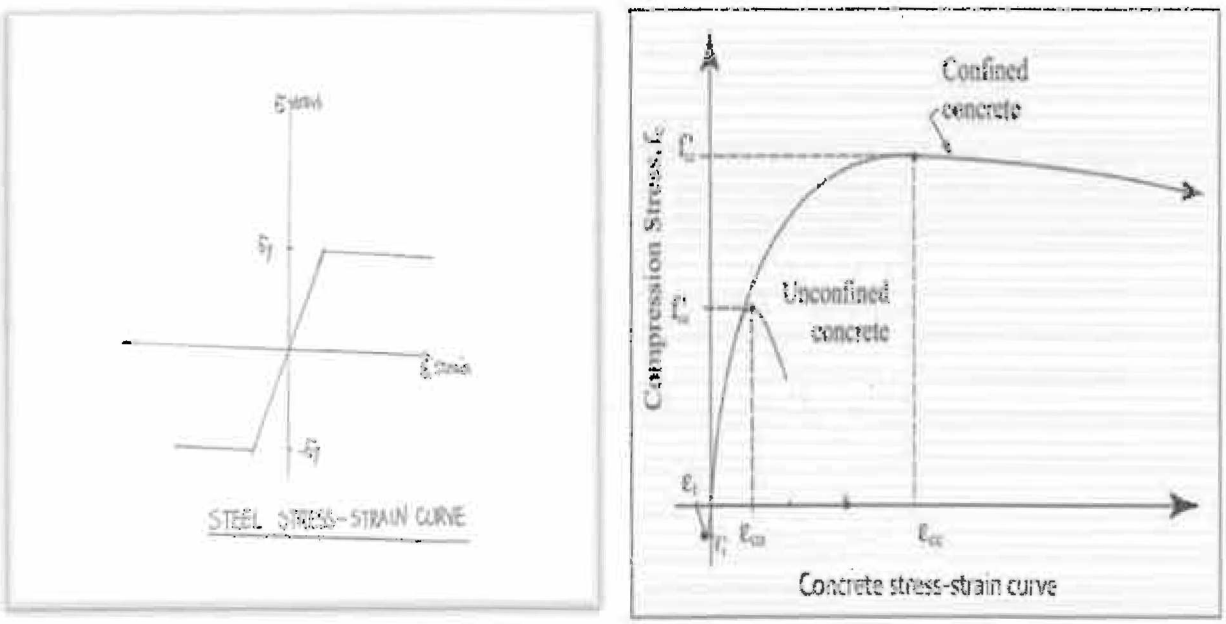


Fig.1 Geometry

2.2 Material modelling

2.2.1 Steel Tube and Steel Reinforcing

In this analysis, steel tube and reinforcing bars are modelled by the perfectly elastic plastic model using the Poisson's ratio vs=0.3 and Young's Modulus Es=29*10^{6}6 psi; the yield strength is 50 ksi and the unit weight is 486.94 pcf.



(a) Steel stress-strain curve (b) Concrete stress-strain curve

Fig.2 Stress-strain Relationship

2.2.2 Concrete model

The Poisson's ratio of concrete is assumed to be 0.15 and the unit weight of concrete is 145 pcf and dilation angle ψ is 36.31°. The modulus of elasticity: Ec=57,000$\sqrt{fcu}$, where fcu is the compressive strength of concrete.

ABAQUS requires input of elastic strain and yield stress. The plastic strain is calculated using Eq. (1) as illustrated in Fig.3.

$$\varepsilon pl = \varepsilon - \frac{fc}{Ec} \tag{1}$$

where εpl represents plastic strain and fc is the stress corresponding to each strain ε.

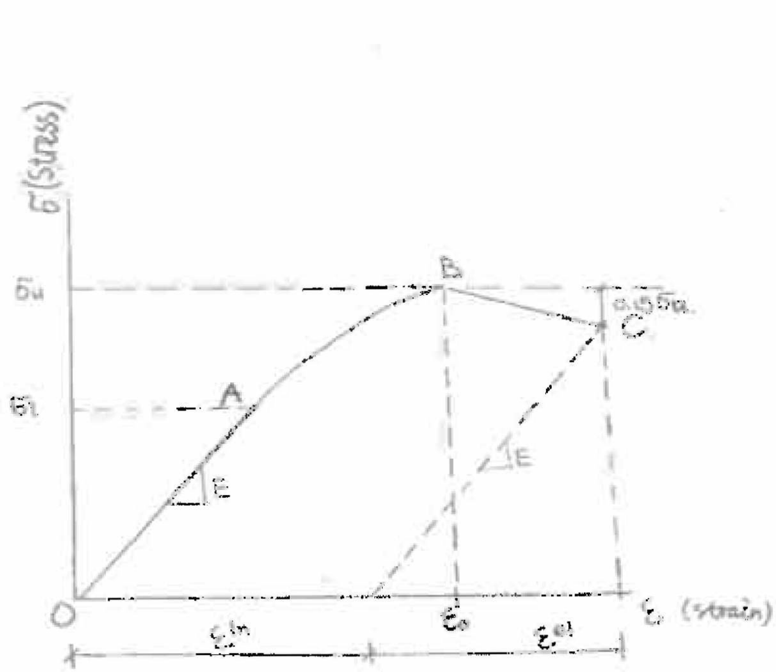


Fig.3 Concrete model utilized in ABAQUS

In this study, two concrete models are utilized: unconfined and confined concrete. As shown in Fig.4, the confined concrete model has higher strength. The detailed discussion is as follows.

<u>CASE1. Unconfined concrete model</u>

As shown in Fig.4, curve OAB presents the unconfined concrete model used in the present study.

The strain εc' corresponding to the compressive strength fc' is calculated by Eq. (2):

$$\varepsilon c' = 1.8\frac{fc'}{Ec} \tag{2}$$

For part OA, the stress fc and strain ε are related by Eq. (3):

$$fc = fc'\left[\frac{2\varepsilon}{\varepsilon c'} - \left(\frac{\varepsilon}{\varepsilon c'}\right)^2\right] \tag{3}$$

For part AB: it is linear. The difference of stress between AB is 0.15fc'.

The detailed calculations are shown in Appendix 1.

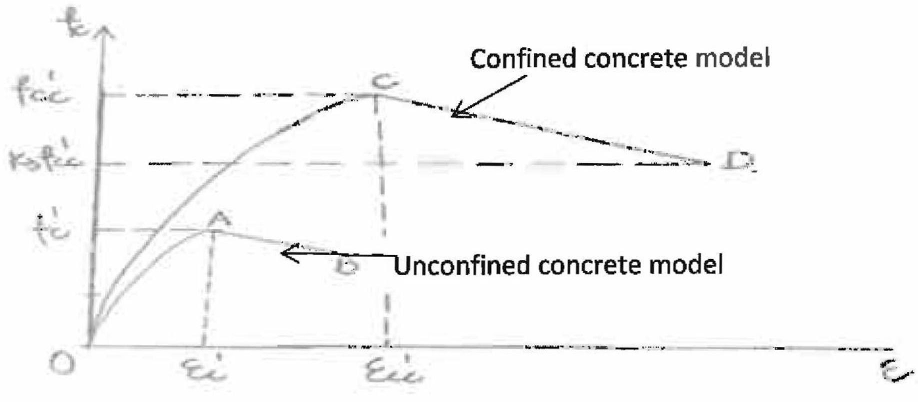


Fig.4 Confined and Unconfined Concrete Models

CASE2. Confined concrete model

As shown in Fig.4, curve OCD presents the confined model.

The compressive strength is calculated using this equation:

$$fcc' = fc' + k1 \cdot fl \tag{4}$$

The corresponding strain is calculated using this equation:

$$\varepsilon cc' = \varepsilon c'(1 + k2\frac{fl}{fc'}) \tag{5}$$

where fl represents confining pressure around the concrete core, which is calculated using Eq.(6):

$$\frac{fl}{fc'} = 0.055048 - 0.001885\frac{B}{t} \quad (17 \leq B/t \leq 29.2) \tag{6}$$

Where B represents the width of cross-section; t represents the thickness of the tube.

In the present study, K1=4.1 and K2= 20.5 based on the studies of Richart et al.(1928).

For curve OC, the stress fc is calculated using Eq. (7):

$$fc = \frac{Ec \cdot \varepsilon}{1+(R+RE-2)\left(\frac{\varepsilon}{\varepsilon cc'}\right)-(2R-1)\left(\frac{\varepsilon}{\varepsilon cc'}\right)^2+R\left(\frac{\varepsilon}{\varepsilon cc'}\right)^3} \tag{7}$$

where R and RE are calculated using the following equations:

$$R = \frac{RE(R\sigma-1)}{(R\varepsilon-1)^2} - \frac{1}{R\varepsilon} \tag{8}$$

$$RE = \frac{Ec \cdot \varepsilon cc'}{fcc'} \tag{9}$$

where $R\sigma$ =4, $R\varepsilon$ =4 (Hu and Schnobrich 1989).

For curve CD, the stress strain curve is linear and the stress ends at fc which is calculated usingequation fc=K3·fcc', where K3 is calculated using Eq(1):

$$K3 = 0.000178\left(\frac{B}{t}\right)^2 - 0.02492\left(\frac{B}{t}\right) + 1.2722 \quad (17 \leq B/t \leq 70) \tag{10}$$

The detailed calculations are shown in Appendix 2.

2.3 Interface

In order for the tube and concrete core to behave as a single member instead of two different parts, a contact property, which is tangential behavior, is defined between the two material surfaces (The master surface is the outer surface of concrete column; and the slave surface is the inner surface of the tube). This tangential behavior is provided using friction, with a coefficient of 0.2.

2.4 Mesh

The mesh size for the concrete is 2.4 × 2.4 × 2.4 (inch) and 2 × 2 × 0.5. (inch) for the steel tube as shown in Fig. 5.

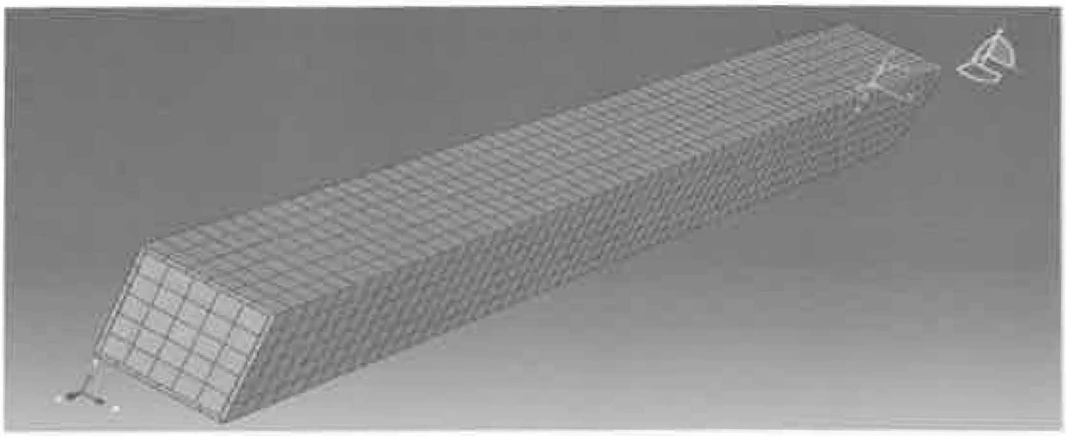


Fig 5 Meshed CFT column

2.5 Constraints

2.5.1 Embedment

Constraint between concrete and reinforcement is defined as embedded because the embedded technique can be used for a set of truss or beam elements that are embedded in a set of solid elements.

2.5.2 Coupling

On both ends of the column, a reference point is defined and a kinematic coupling constraint is utilized, which limits the motions of a group of nodes to a rigid body motion defined by that reference node.

2.6 Loading and boundary condition

The bottom of the column is assumed to be a pinned end. The top of the column is assumed to be a pinned end allowing longitudinal movement of the column with free rotation around the x-axis.

In this study, a displacement loading method is used. The top of the column is displaced by the amount from Eq. (11).

$$\Delta = \varepsilon \cdot L \tag{11}$$

where Δ represents the displacement, L is the length of the column (120 inches), and ε is the strain at when the concrete fails. After calculation, 0.36 inches is used for the pure reinforced concrete column model and for the CFT column which uses the unconfined concrete material model; 0.72 inches is used for the CFT column which uses the confined concrete material model.

3. Results

The goal is to find the capacity of the columns. The stresses of the elements in the middle of the column are extracted from the results of ABAQUS analysis. Then Eq. (12) is used to find the force P and Moment M. The axial force P is calculated as the sum of forces calculated for each element from concrete and steel.

$$P = \sum_{i=1}^{n} fci \cdot Ai + \sum_{i=I}^{n} fsi \cdot Asi \qquad (12)$$

where fci is the stress of each element corresponding to when the concrete strain reaches 0.003, Ai is the area of each element of concrete, fsi is steel stress, and Asi is area of the steel.

The moment M is the sum of moments for each element of concrete and steel as the following equation shows.

$$M = \sum_{i=1}^{n} fci \cdot Ai \cdot Li + \sum_{i=1}^{n} fsi \cdot Asi \cdot Li2 \qquad (13)$$

where Li is the moment arm for each concrete element and $Li2$ is the moment arm for each steel element.

3.1 Analysis for pure reinforced concrete column without a tube

The P-M diagram for the pure reinforced concrete column without a steel tube is generated. The aim is to use this P-M diagram as a comparison base to the results from ABAQUS Analysis.

P-M interaction diagram

In Fig. 6, Point A stands for M equals 0 case; the column is in pure compression. Point B stands for the situation when the concrete strain reaches 0.003. Point C stands for the yielding of the steel. Point D stands for the situation when the steel strain reaches 0.005.

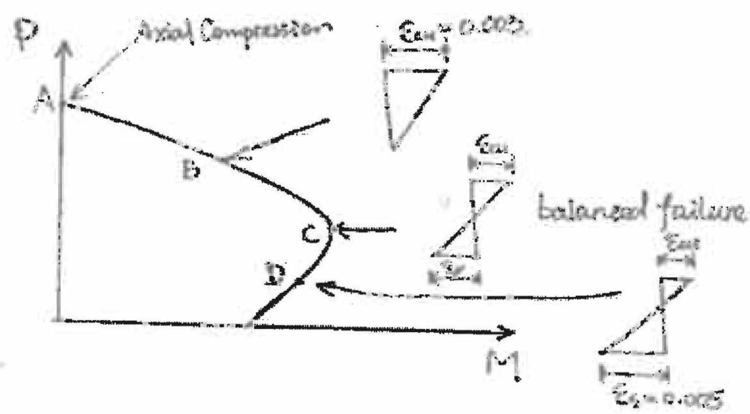


Fig 6. P-M diagram for reinforced concrete

3.1.2 Comparisons of Results for reinforced concrete (without tube) between spcolumn and ABAQUS.

In ABAQUS analysis two cases are executed. One is with concentric loading; the other is with eccentric loading of an eccentricity of 2 inches. The corresponding results are shown in Fig 7. The left top star represents the axial and the lower star represents the column with eccentric loading. The detailed calculations can be found in Appendix 3.

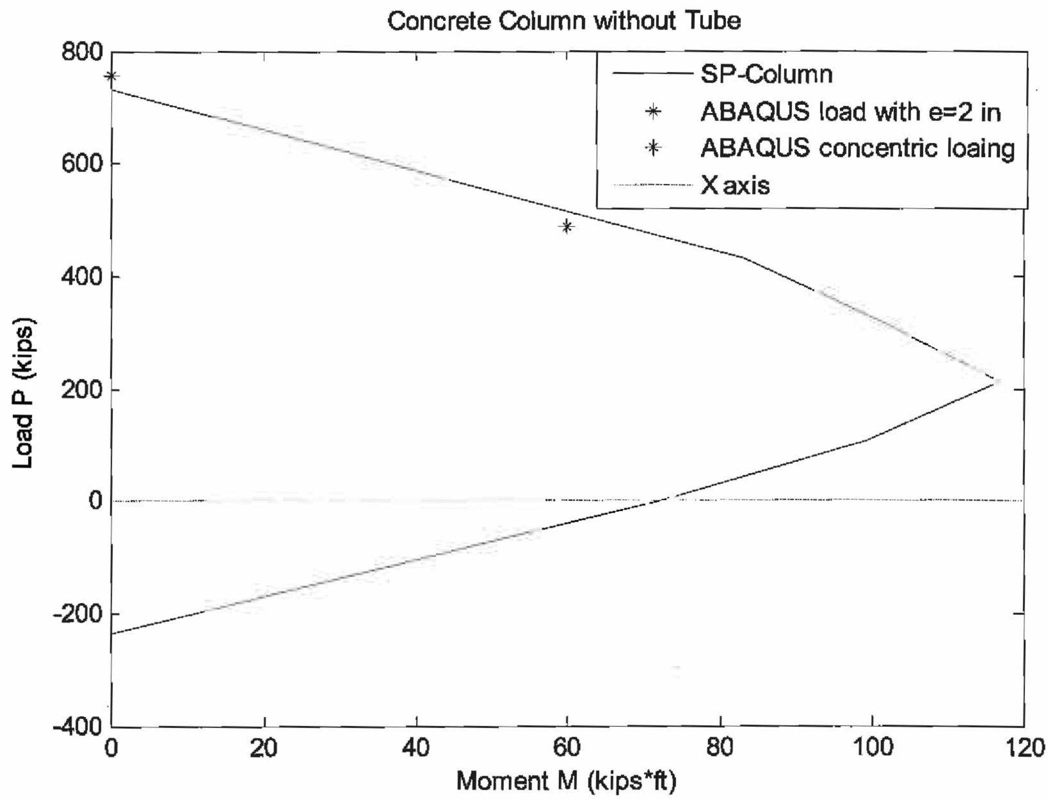


Fig 7. P-M diagram for RC column using spColumn and ABAQUS

As it shows in Fig. 7, the ABAQUS results validate with spColumn results.

3.2 Analysis

3.2.1 Stress-strain curve

Stress-strain curves are generated and shown in Figs. 8 and 9 using ABAQUS for both cases: confined concrete material model and unconfined concrete material model. Thus they show the material models used in ABAQUS follow the ones defined in Section 2.2.2.

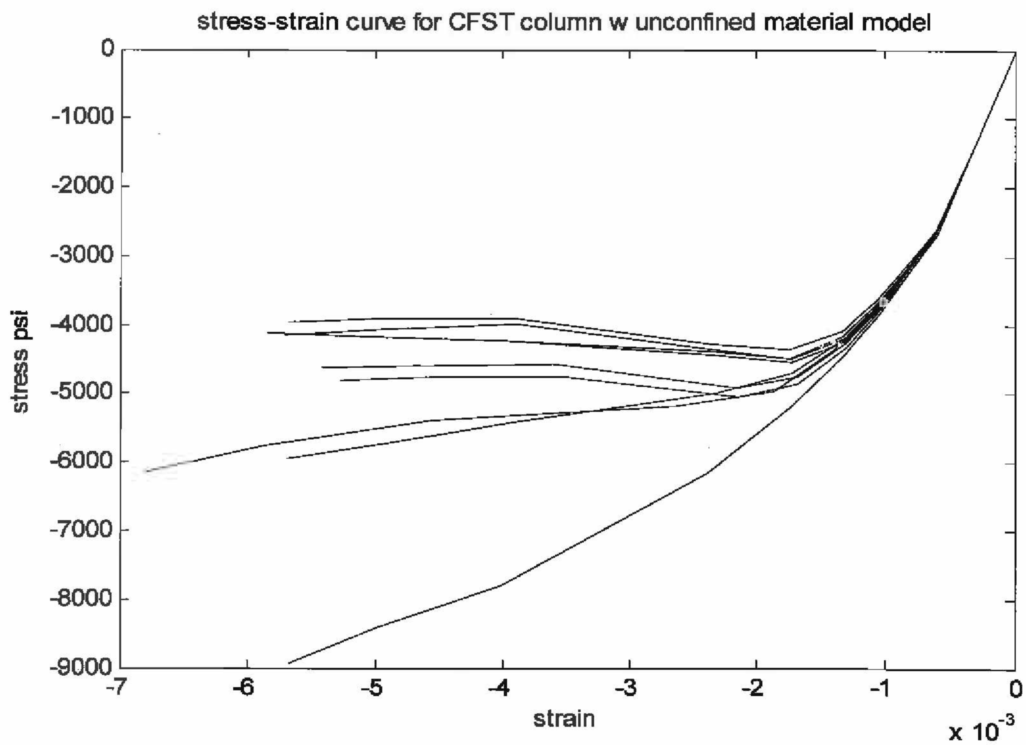


Fig 8. Stress-Strain Curve for CFT using unconfined concrete material

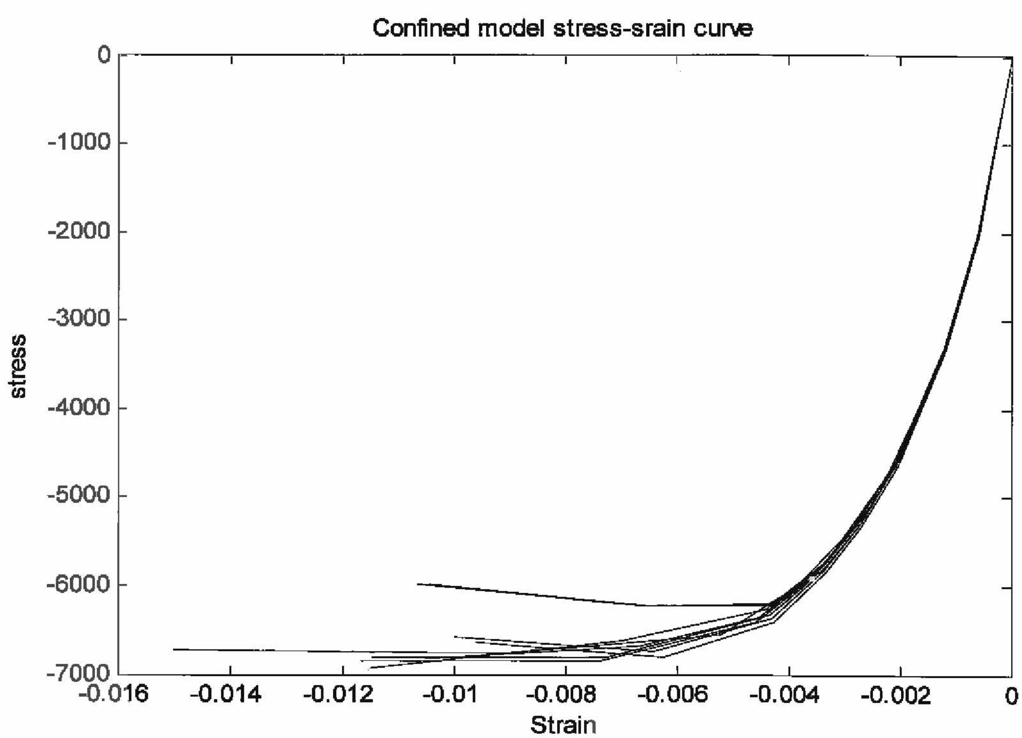


Fig 9. Stress-Strain Curve for CFT using confined concrete material

3.2.2 Capacity calculation

Since the steel tube is added, the force and moment from the steel tube are added as well. Axial force P is calculated using the following equation:

$$P = \sum_{i=1}^{n} fci \cdot Ai + \sum_{i=1}^{n} fsi \cdot Asi + \sum_{i=1}^{n} Fsi \cdot Assi \tag{14}$$

where *Fsi* and *Assi* are the steel tube element stress and area; respectively.

The moment M is calculated using the following equation:

$$M = \sum_{i=1}^{n} fci \cdot Ai \cdot Li + \sum_{i=1}^{n} fsi \cdot Asi \cdot Li2 + \sum_{i=1}^{n} Fsi \cdot Assi \cdot Li3 \tag{15}$$

In appendices 4 and 5, the stress and strain for each element and detailed calculations of force P and Moment M can be found.

4. Results and Conclusion

A reinforced column capacity can be calculated by Eq (16)

$$\mathrm{P} = 0.85 \cdot \mathrm{fc'} \cdot (\mathrm{Ag} - \mathrm{As}) + \mathrm{fy} \cdot \mathrm{As} \tag{16}$$

For a steel tube after yielding, the force from the tube can be calculated using the following equation:

$$\mathrm{Pst} = \mathrm{fy} \cdot \mathrm{Ast} \tag{17}$$

Thus adding these two parts together, a force P= 1832.6 kips is calculated.

Compare to the results from ABAQUS:

- Unconfined concrete model: P=2030 kips
- Confined concrete model: P=2300 kips

For the CFT column, the strength of the columns is not a simple summation of strengths generated from core concrete and steel tube. Furthermore, the strength of CFT columns gets higher because of the confinement effect of the steel tube.

The original goal of this project is to generate a P-M interaction curve for CFT columns. However, since the eccentric loading case results are off than expected, they are not included in this report. The future research should address the following issues:

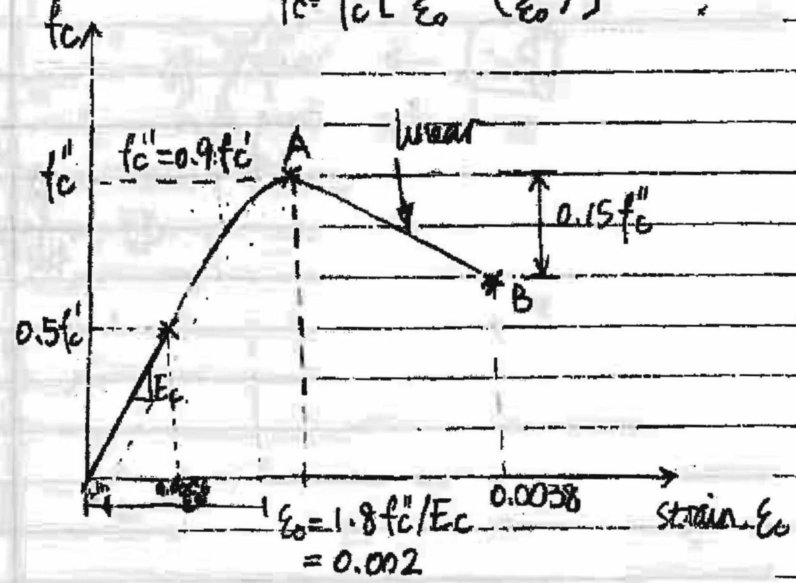
- material models for steel and concrete;
- Mesh size and its influences on the convergence of results.
- The influence of the thickness of the steel tubes on the CFT column capacity.

References:

1. Richart F.E., et.al. (1928). *A study of the Failure of Concrete Under Combined Compression Stresses*. University of Illinois Engineering Experimental Station, Bulletin No.185, p.104.
2. Simulia. (2014) *Abaqus Analysis User's Manual.* www.maths.cam.ac.uk/computing/software_docs/docs/v6.12/books/usb/default.htm
3. Wight, J. K. and MacGregor, J. G. (2012) *Reinforced Concrete Mechanics & Design 6E,* Pearson Educatin, Inc.
4. Hu, H.-T. and Schnobrich, W.C. (1989). Constitutive modeling of concrete by using nonassociated plasticity. *J. Mater.Viv.Eng.,* 1(4), pp.199-216.

Appendix 1. Unconfined Concrete Model, Stress-Strain Calculations

$$f_c = f''_c\left[\frac{2\varepsilon_c}{\varepsilon_o} - \left(\frac{\varepsilon_c}{\varepsilon_o}\right)^2\right]$$



$f'_c = 5$ ksi ; $f''_c = 0.9 * f'_c = 4.5$ ksi ; $0.85 f''_c = 0.85 * 4.5 = 3.825$ ksi

$E_c = 57{,}000\sqrt{f'_c} = 57{,}000\sqrt{5000} = 4030508.653$ psi

$\varepsilon_o = 1.8 f''_c / E_c = 1.8 * 4.5 / 4030.5 = 0.002$

$A(0.002, 4.5)$; $B(0.0038, 3.8)$

For AB: $f_c = K * \varepsilon_c + b$

$$\begin{cases} 4.5 = K * 0.002 + b \\ 3.8 = K * 0.0038 + b \end{cases} \Rightarrow \begin{cases} K = -388.9 \\ b = 5.28 \end{cases}$$

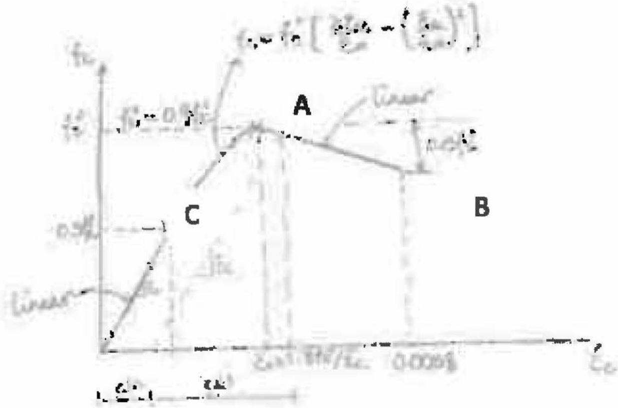
$$\Rightarrow f_c = -388.9 * \varepsilon_c + 5.28$$

$$E_c = \frac{0.5 f'_c}{\varepsilon_c} = \frac{0.5 * 5^{(ksi)}}{\varepsilon_c} = 4030.51^{(ksi)} \Rightarrow \varepsilon_c = 0.00062027$$

	εc	fc	εel	εln
	0.0006	2500	0	0.0006
	0.0007	2598.75	0.00064477	0.0000552
	0.0008	2880	0.00071455	0.0000854
	0.0009	3138.75	0.000778748	0.0001213
	0.0010	3375	0.000837363	0.0001626
	0.0011	3588.75	0.000890396	0.0002096
	0.0012	3780	0.000937847	0.0002622
AC	0.0013	3948.75	0.000979715	0.0003203
	0.0014	4095	0.001016001	0.0003840
	0.0015	4218.75	0.001046704	0.0004533
	0.0016	4320	0.001071825	0.0005282
	0.0017	4398.75	0.001091363	0.0006086
	0.0018	4455	0.00110532	0.0006947
	0.0019	4488.75	0.001113693	0.0007863
	0.002	4500	0.001116484	0.0008835
	0.0021	4463.31	0.001107381	0.0009926
	0.0022	4424.42	0.001097732	0.0011023
	0.0023	4385.53	0.001088084	0.0012119
	0.0024	4346.64	0.001078435	0.0013216
	0.0025	4307.75	0.001068786	0.0014312
	0.0026	4268.86	0.001059137	0.0015409
	0.0027	4229.97	0.001049488	0.0016505
	0.0028	4191.08	0.001039839	0.0017602
AB	0.0029	4152.19	0.001030190	0.0018698
	0.003	4113.3	0.001020541	0.0019795
	0.0031	4074.41	0.001010892	0.0020891
	0.0032	4035.52	0.001001243	0.0021988
	0.0033	3996.63	0.000991594	0.0023084
	0.0034	3957.74	0.000981946	0.0024181
	0.0035	3918.85	0.000972297	0.0025277
	0.0036	3879.96	0.000962648	0.0026374
	0.0037	3841.07	0.000952999	0.0027470
	0.0038	3802.18	0.000943350	0.0028567

AC: $fc=fc``*[2*\varepsilon c/\varepsilon o-(\varepsilon c-\varepsilon o)^2]$

$\varepsilon ln=\varepsilon o-\varepsilon el$;
$\varepsilon el=fc/Ec$;
$Ec=57000*\sqrt{5000}$

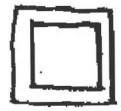


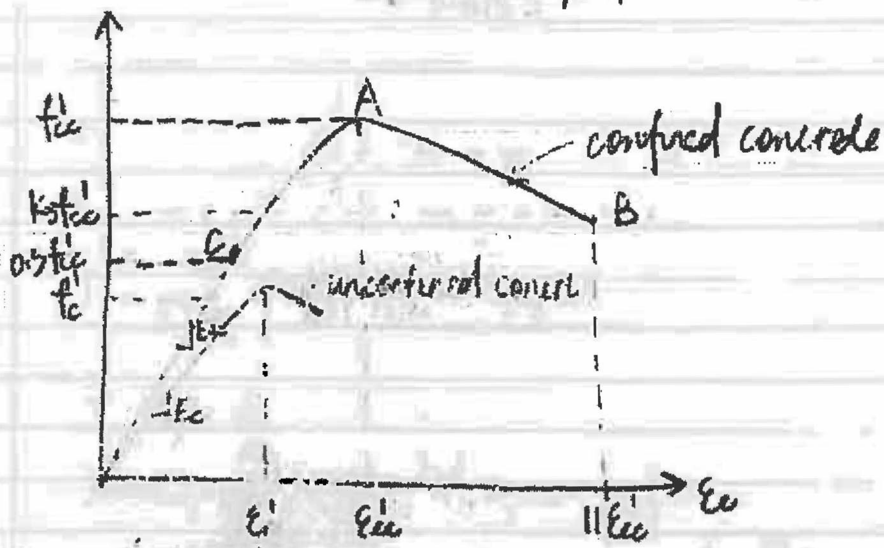
$AB: fc = (-388.9 * \varepsilon c+5.28)*1000$

Appendix 2 Confined Model, Calculations

$1\,MPa = 145\,psi$
$= 0.145\,ksi$
$1\,ksi = 6.89\,MPa$

Confined Concrete

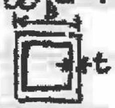




(34.47 MPa) (31 MPa)

$f_{cu} = 5\,ksi$; $f'_c = 0.9 * f_{cu} = 0.9 * 5 = 4.5\,ksi$

$\varepsilon'_c = 1.8 f'_c / E_c = 1.8 * 4.5 / 4030.5 = 0.002$ ✓



$B/t = 12/0.5 = 24$ (17, 29.2)

$f_l/f_y = 0.055048 - 0.001885(B/t)$
$= 0.055048 - 0.001885 * 24 = 0.05504 - 0.04524 = 0.0098$
$f_y = 50\,ksi$ (344 MPa)

$\Rightarrow f_l = 344_{MPa} * 0.0098 = 3.38\ MPa = 0.49\,ksi$

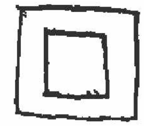
$f'_{cc} = f'_c + K_1 f_l = 31 + 4.1 * 3.38 = 44.9\,MPa = 6.5\,ksi$ ✓
$K_1 = 4.1$

$0.5 f'_{cc} = 0.5 * 6.509 = 3.2545\,ksi$ ✓

$\varepsilon'_{cc} = \varepsilon'_c \left(1 + K_2 * f_l / f'_c\right) = 0.002 * (1 + 20.5 * 0.49/4.5) = 0.006$ ✓
$K_2 = 20.5$ ✓

$1\,MPa = 0.145\,ksi$

Confined Concrete



For Confined Concrete:

$$E_{cc} = 4700\sqrt{f'_{cc}} = 4700\sqrt{44.9_{MPa}} = 31493.5\ MPa = 4566.6\ ksi$$

$$f_c = \frac{E_{cc}\varepsilon_c}{1+(R+R_E-2)\left(\frac{\varepsilon_c}{\varepsilon'_{cc}}\right)-(2R-1)\left(\frac{\varepsilon_c}{\varepsilon'_{cc}}\right)^2+R\left(\frac{\varepsilon_c}{\varepsilon'_{cc}}\right)^3}$$

$$R = \frac{R_E(R_\sigma-1)}{(R_\varepsilon-1)^2} - \frac{1}{R_\varepsilon}, \quad R_E = \frac{E_c\varepsilon'_{cc}}{f'_{cc}} = \frac{4566.6 * 0.006}{6.5} = 4.2$$

$R_\sigma = 4,\ R_\varepsilon = 4$

$$R = \frac{4.2*(4-1)}{(4-1)^2} - \frac{1}{4} = 1.16$$

$$f_c = \frac{4566600 * \varepsilon_c}{1+(1.16+4.2-2)\left(\frac{\varepsilon_c}{0.006}\right)-(2*1.16-1)\left(\frac{\varepsilon_c}{0.006}\right)^2+1.16*\left(\frac{\varepsilon_c}{0.006}\right)^3}$$

$A(0.006,\ \cancel{6509.17}\ 6523.71)$

$K_3 = 0.000178(B/t)^2 - 0.02492(B/t) + 1.2722 \quad (17 \le B/t \le 70)$
$= 0.000178 * 24^2 - 0.02492*24 + 1.2722$
$= 0.78$ ✓

$K_3 f'_{cc} = 0.78 * \cancel{6509.17}\ 6523.71 = \cancel{5055.3}\ 5088.5\ ksi$ ✓
$11\varepsilon'_{cc} = 11 * 0.006 = 0.066$ ✓

$B(0.066,\ 5088.3)$

$y = kx + b$

$$\begin{cases} 6523.71 = k*0.006 + b \\ 5088.3 = k*0.066 + b \end{cases} \Rightarrow \begin{cases} k = -2194.82 \\ b = 6536.88 \end{cases} \Rightarrow y = -2194.82x + 6655.25$$

this is for OA

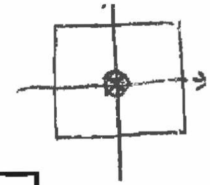
	ε	f	εel	εpl
1	0.0001	434.1749	9.44E-05	5.59E-06
2	0.0002	822.9266	0.000179	2.11E-05
3	0.0003	1173.71	0.000255	4.48E-05
4	0.0004	1492.414	0.000325	7.55E-05
5	0.0005	1783.751	0.000388	0.000112
6	0.0006	2051.534	0.000446	0.000154
7	0.0007	2298.881	0.0005	0.0002
8	0.0008	2528.367	0.00055	0.00025
9	0.0009	2742.133	0.000596	0.000304
10	0.001	2941.975	0.00064	0.00036
11	0.0011	3129.41	0.000681	0.000419
12	0.0012	3305.725	0.000719	0.000481
13	0.0013	3472.023	0.000755	0.000545
14	0.0014	3629.247	0.000789	0.000611
15	0.0015	3778.214	0.000822	0.000678
16	0.0016	3919.632	0.000852	0.000748
17	0.0017	4054.116	0.000882	0.000818
18	0.0018	4182.204	0.000909	0.000891
19	0.0019	4304.367	0.000936	0.000964
20	0.002	4421.022	0.000961	0.001039
21	0.0021	4532.532	0.000986	0.001114
22	0.0022	4639.223	0.001009	0.001191
23	0.0023	4741.381	0.001031	0.001269
24	0.0024	4839.262	0.001052	0.001348
25	0.0025	4933.094	0.001073	0.001427
26	0.0026	5023.079	0.001092	0.001508
27	0.0027	5109.4	0.001111	0.001589
28	0.0028	5192.219	0.001129	0.001671
29	0.0029	5271.685	0.001146	0.001754
30	0.003	5347.929	0.001163	0.001837
31	0.0031	5421.071	0.001179	0.001921
32	0.0032	5491.219	0.001194	0.002006

	ε	f	εel	εpl
33	0.0033	5558.471	0.001209	0.002091
34	0.0034	5622.916	0.001223	0.002177
35	0.0035	5684.637	0.001236	0.002264
36	0.0036	5743.706	0.001249	0.002351
37	0.0037	5800.193	0.001261	0.002439
38	0.0038	5854.161	0.001273	0.002527
39	0.0039	5905.667	0.001284	0.002616
40	0.004	5954.766	0.001295	0.002705
41	0.0041	6001.506	0.001305	0.002795
42	0.0042	6045.936	0.001315	0.002885
43	0.0043	6088.099	0.001324	0.002976
44	0.0044	6128.036	0.001333	0.003067
45	0.0045	6165.787	0.001341	0.003159
46	0.0046	6201.389	0.001349	0.003251
47	0.0047	6234.877	0.001356	0.003344
48	0.0048	6266.287	0.001363	0.003437
49	0.0049	6295.651	0.001369	0.003531
50	0.005	6323.002	0.001375	0.003625
51	0.0051	6348.371	0.00138	0.00372
52	0.0052	6371.789	0.001386	0.003814
53	0.0053	6393.287	0.00139	0.00391
54	0.0054	6412.894	0.001395	0.004005
55	0.0055	6430.64	0.001398	0.004102
56	0.0056	6446.555	0.001402	0.004198
57	0.0057	6460.668	0.001405	0.004295
58	0.0058	6473.01	0.001408	0.004392
59	0.0059	6483.608	0.00141	0.00449
60	0.006	6492.493	0.001412	0.004588
61	0.0061	6499.696	0.001413	0.004687
62	0.0062	6505.244	0.001415	0.004785
63	0.0063	6509.17	0.001415	0.004885
64	0.0064	6511.503	0.001416	0.004984
65	0.0065	6512.274	0.001416	0.005084

this is for BC

	ε	f	εel	εpl
1	0.007	6492.936	0.001412	0.005588
2	0.014	6330.622	0.001377	0.012623
3	0.021	6168.308	0.001341	0.019659
4	0.028	6005.994	0.001306	0.026694
5	0.035	5843.68	0.001271	0.033729
6	0.042	5681.366	0.001235	0.040765
7	0.049	5519.052	0.0012	0.047800
8	0.056	5356.738	0.001165	0.054835
9	0.063	5194.424	0.00113	0.061870
10	0.07	5032.11	0.001094	0.068906
11	0.077	4869.796	0.001059	0.075941

Reinforced Concrete without tube Model — concentric



Concentric

Stress

E-1 E: 126 IP: 1	E-1 E: 127 IP: 1	E-1 E: 128 IP:	E-1 E: 377 IP: 1	E-1 E: 378 IP	E-1 E: 628 IP: 1
-4.09E+03	-4.35E+03	-4.40E+03	-4.37E+03	-4.05E+03	-4.39E+03

1126	876	626	376	126
1127	877	627	377	127
1128	878	628	378	128
1129	879	629	379	129
1130	880	630	380	130

Concrete:

Total Stress $= (-4090-4350-4400*2-4050-4370)*4$
-4390
$= -518$ kips

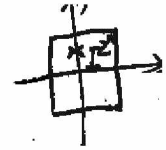
Steel:

Total stress $= 50*4.76 = -238$ kips.

Total $= -518-238 = -756$ kips

Appendix 5

Reinforced Concrete without tube Model — 2" eccentricity



Concrete

Elements:						arm		
1126	876	626	376	126		3.9		
1127	877	627	377	127		1.7		
1128	878	628	378	128		0		
1129	879	629	379	129		1.7		
1130	880	630	380	130		3.9		
stress					Tstress	Tforce(kips)	Mx	
-4.35E+03	-5.31E+03	-3.76E+03	-5.31E+03	-4.35E+03	-2.31E+04	-1.12E+02	-3.63E+01	
-4.37E+03	-6.66E+03	-3.33E+03	-6.66E+03	-4.37E+03	-2.54E+04	-1.23E+02	-1.74E+01	
-3.06E+03	-2.05E+03	-6.67E+03	-2.05E+03	-3.06E+03	-1.69E+04	-8.17E+01	0.00E+00	
-9.96E+02	-7.58E+02	5.43E+02	-758.421	-995.721	-2.97E+03	-1.44E+01	2.03E+00	
2.99E+02	4.37E+02	512.161	437.29	299.34	1.99E+03	9.61E+00	-3.12E+00	
							TMx=	-5.48E+01

concrete

Total sress	-6.63E+04	psi
total force	-3.21E+02	kips
total Mx	-5.48E+01	kips*ft

steel rebar

E117	E415	E411	E25	E403	E407
-5.00E+04	-5.00E+04	-5.00E+04	-5.53E+03	-4.73E+03	-5.53E+03
Total force	-1.66E+02	kips			
Mtop=	1.19E+02	kips*ft			
Mbottome=	-4.00E+00	kips*ft			
Mxtotal=	1.15E+02	kips*ft			

Total P=	-4.87E+02	kips
Total Mx=	6.02E+01	kips*ft

Appendix4 Calculations for CFST Column with unconfined Concrete Material

Concrete

Elements:				
1126	876	626	376	126
1127	877	627	377	127
1128	878	628	378	128
1129	879	629	379	129
1130	880	630	380	130

arm
3.9
1.7
0
1.7
3.9

stress

					Tstress	Tforce(kips)	Mx
-4.97E+03	-4.69E+03	-4.55E+03	-4.69E+03	-4.97E+03	-2.39E+04	-1.16E+02	-3.75E+01
-4.36E+03	-4.48E+03	-5.19E+03	-4.48E+03	-4.85E+03	-2.34E+04	-1.13E+02	-1.60E+01
-4.85E+03	-4.69E+03	-4.55E+03	-4.69E+03	-4.36E+03	-2.31E+04	-1.12E+02	0.00E+00
-4.36E+03	-4.48E+03	-4.76E+03	-4.48E+03	-4.97E+03	-2.31E+04	-1.12E+02	1.58E+01
-4.97E+03	-4.97E+03	-4.48E+03	-4.76E+03	-4.48E+03	-2.37E+04	-1.14E+02	3.72E+01
						TMx=	-5.45E-01

concrete

Total sress	-1.17E+05	psi
total force	-5.67E+02	kips
total Mx	-5.45E-01	kips*ft

steel rebar

E117	E415	E411	E25	E403	E407
-5.00E+04	-5.00E+04	-4.96E+04	-5.00E+04	-5.00E+04	-4.96E+04
Total force	-2.99E+02	kips			
Mtop=	3.96E+01	kips*ft			
Mbottome=	-3.79E+01	kips*ft			
Mxtotal=	1.66E+00	kips*ft			

Steel Tube

	705	704	703	702	700	699	
718							717
697							716
706							715
707							714
708							701
709							720
	719	698	710	711	712	713	

stress								sub total stress	force	arm
	-4.88E+04	-4.85E+04	-4.87E+04	-4.87E+04	-4.85E+04	-4.88E+04		-2.92E+05	-2.92E+05	5.25
-4.88E+04							-4.88E+04	-9.76E+04	-9.76E+04	5
-4.85E+04							-4.85E+04	-9.71E+04	-9.71E+04	3
-4.86E+04							-4.86E+04	-9.73E+04	-9.73E+04	1
-4.86E+04							-4.86E+04	-9.73E+04	-9.73E+04	1
-4.85E+04							-4.85E+04	-9.71E+04	-9.71E+04	3
-4.88E+04							-4.88E+04	-9.76E+04	-9.76E+04	5
	-4.88E+04	-4.85E+04	-4.87E+04	-4.87E+04	-4.85E+04	-4.88E+04		-2.92E+05	-2.92E+05	5.25

	Moment
	-1.28E+02
	-4.07E+01
	-2.43E+01
	-8.11E+00
	8.11E+00
	2.43E+01
	4.07E+01
	1.28E+02
total Mom	0.00E+00

Total stress	
-1.17E+06	psi
-1.17E+03	ksi

Total force	
-1.17E+03	kips

Total P=	-2.03E+03	kips
Total Mx=	1.12E+00	kips*ft

Appendix 5 Calculations for CFST Column with Compliant Concrete Material

Concrete

Elements:				
1126	876	626	376	126
1127	877	627	377	127
1128	878	628	378	128
1129	879	629	379	129
1130	880	630	380	130

arm
3.9
1.7
0
1.7
3.9

stress					Tstress	Tforce(kips)	Mx
-6.72E+03	-6.84E+03	-6.58E+03	-6.84E+03	-6.72E+03	-3.37E+04	-1.63E+02	-5.30E+01
-6.80E+03	-6.83E+03	-5.98E+03	-6.83E+03	-6.80E+03	-3.32E+04	-1.61E+02	-2.28E+01
-6.64E+03	-5.99E+03	-6.93E+03	-5.99E+03	-6.64E+03	-3.22E+04	-1.56E+02	0.00E+00
-6.80E+03	-6.83E+03	-5.98E+03	-6.83E+03	-6.80E+03	-3.32E+04	-1.61E+02	2.28E+01
-6.72E+03	-6.84E+03	-6.58E+03	-6.84E+03	-6.72E+03	-3.37E+04	-1.63E+02	5.30E+01
						TMx=	-2.47E-03

concrete

Total sress	-1.66E+05	psi
total force	-8.04E+02	kips
total Mx	-2.47E-03	kips*ft

steel rebar

E117	E415	E411	E25	E403	E407
-5.00E+04	-5.00E+04	-5.00E+04	-5.00E+04	-5.00E+04	-5.00E+04
Total force	-3.00E+02	kips			
Mtop=	3.97E+01	kips*ft			
Mbottome=	-3.80E+01	kips*ft			
Mxtotal=	1.67E+00	kips*ft			

Steel Tube

	705	704	703	702	700	699	
718							717
697							716
706							715
707							714
708							701
709							720
	719	698	710	711	712	713	

stress

	-49583.8	-50067.2	-49686.5	-49609.4	-49707.8	-49739	
-50067.2							-50126.5
-49686.5							-50130.7
-49583.8							-49707.9
-49718.5							-49600.3
-50126.5							-49635.6
-49609.4							-50130.60
	-50130.6	-50057	-49635.7	-49739	-50057	-49600.3	

Total stress	
-1.20E+06	psi
-1.20E+03	ksi

Total force	
-1.20E+03	kips

Total P=	-2.30E+03	kips